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THE EFFECTS OF OZONE ON PLANTS IN THE UNITED STATES

by

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16. ABSTRACT

Foliar injury to vegetation is one of the earliest and most obvious manifestations of O3 injury. However, the O3 effects are not limited to visible injury; impacts can range from reduced plant growth, decreased yield, changes in crop quality and alterations in susceptibility to abiotic and biotic stresses. The plant foliage is the primary site of O3 effects, although significant secondary effects can occur throughout the plant.

Ozone has been identified as the most important phytotoxic air pollutant in terms of area impacted and as a cause of reduced plant performance. Ozone is an imposed environmental variable that can be detected, monitored and sometimes quantified by observing specific responses on sensitive plants. Ozone impacts a wide range of plant species; these O3-sensitive species and cultivars are distributed throughout the United States. Although O3 has been shown to reduce plant yields, more research is needed to estimate yield loss for additional cultivars and species. More information is needed to determine the characteristics of the exposure that are most important in causing a plant response. Studies need to be conducted to determine the influence of major environmental factors on O3-response thresholds.

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THE EFFECTS OF OZONE ON PLANTS IN THE UNITED STATES

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Foliar injury on vegetation is one of the earliest and most obvious manifestations of O_3 injury. However, the O_3 effects are not limited to visible injury; impacts can range from reduced plant growth, decreased yield, changes in crop quality and alterations in susceptibility to abiotic and biotic stresses. The plant foliage is the primary site of O_3 effects although significant secondary effects can occur throughout the plant.

Ozone exerts a phytotoxic effect only if a sufficient amount reaches the sensitive cellular sites within the leaf. The O_3 diffuses from the ambient air into the leaf through the stomata, which can exert some control on O_3-uptake, to the active sites within the leaf. Ozone injury will not occur if 1) the rate of O_3 uptake is low enough so the plant can detoxify or metabolize O_3 or its metabolites, or 2) the plant is able to repair or compensate for the O_3 impacts (Tingey and Taylor, 1982). This is analogous to the plant response to SO_2 (Thomas et al., 1950). Cellular disturbances that are not repaired or compensated are ultimately expressed as visible injury to the leaf or as secondary effects that can be expressed as reduced root growth and/or reduced yield of fruits or seeds.

Plant growth and yield is the end product of a series of biochemical and physiological processes related to uptake, assimilation, biosynthesis and translocation. Sunlight drives the processes that convert carbon dioxide into organic compounds (assimilation) necessary for plant growth and development. In addition to photosynthesis, the plant must extract the essential mineral nutrients and water from the soil for plant growth. Plant organs convert these raw materials into a wide array of compounds required for plant growth and yield. A disruption or reduction in the rates of uptake, assimilation or subsequent biochemical reactions will be reflected in reduced plant growth and yield. Ozone would be expected to reduce plant growth or yield if: (1) it directly impacted the plant process that was limiting plant growth or (2) it impacted another step sufficiently so that this process becomes the step limiting plant growth (Tingey 1977). Conversely, O_3 will not limit plant growth if the process impacted by O_3 is not or does not become rate limiting. This implies that not all effects of O_3 on plants are reflected in growth or yield reductions. These conditions suggest that there are combinations of O_3 concentration and exposure duration that the plant can experience which will not result in visible injury or reduced plant growth and yield. Indeed, numerous studies have demonstrated combinations of concentration

and time that did not cause a significant effect on the plant growth or yield.

LIMITING VALUES OF PLANT RESPONSE

Several approaches have been used to estimate the O_3 concentrations and exposure durations that induce foliar injury. Most of these studies used short-term exposures (less than 1 day) and measured visible injury as the response variable. In one approach to estimate the concentrations and durations that would induce specific amounts of visible injury, plants were exposed to a range of O_3 concentrations and exposure durations and the data were evaluated by regression analysis (Heck and Tingey, 1971). The data for several species were summarized to illustrate the range of concentrations required to induce foliar injury (5 and 20%) on sensitive, intermediate and less sensitive species (Table 1).

TABLE 1. OZONE CONCENTRATIONS FOR SHORT-TERM EXPOSURES THAT PRODUCE 5 OR 20 PERCENT INJURY TO VEGETATION GROWN UNDER SENSITIVE CONDITIONS[a]

Exposure time, hr	Ozone concentrations that may produce 5% (20%) injury, ppm		
	Sensitive plants	Intermediate plants	Less Sensitive plants
0.5	0.35 - 0.50 (0.45 - 0.60)	0.55 - 0.70 (0.65 - 0.85)	≥0.70 (0.85)
1.0	0.15 - 0.25 (0.20 - 0.35)	0.25 - 0.40 (0.35 - 0.55)	≥0.40 (0.55)
2.0	0.09 - 0.15 (0.12 - 0.25)	0.15 - 0.25 (0.25 - 0.35)	≥0.30 (0.40)
4.0	0.04 - 0.09 (0.10 - 0.15)	0.10 - 0.15 (0.15 - 0.30)	≥0.25 (0.35)
8.0	0.02 - 0.04	0.07 - 0.12	≥0.20 (0.30)

[a] The concentrations in parenthesis are for the 20% injury level. Table from U.S. EPA (1978).

An alternative approach to estimate the O_3 concentrations and exposure durations which induce foliar injury is to use limiting value analysis (Jacobson, 1977). The limiting value method was developed from a review of the literature and represents the lowest concentration and exposure duration reported to cause visible injury on various plant species. The analysis was based on more than 100 studies of agricultural crops and 18 studies of tree species. The analysis yielded the following range of concentrations and exposure durations that were likely to induce foliar injury (U.S. EPA, 1978).

Agricultural crops

0.20 to 0.41 ppm for 0.5 h
0.10 to 0.25 ppm for 1.0 h
0.04 to 0.09 ppm for 4.0 h

Trees and shrubs

0.20 to 0.51 ppm for 1.0 h
0.10 to 0.25 ppm for 2.0 h
0.06 to 0.17 ppm for 4.0 h

It should be emphasized that both described approaches estimate concentrations and exposure durations that might induce visible injury but they cannot predict impacts to crop yield or intended use.

The concept of limiting values also was used to estimate the O_3 concentrations and exposure durations which could potentially reduce plant growth and yield (U.S. EPA, 1978). The data were analyzed and plotted in a similar manner to Jacobson's (1977) approach (Figure 1). In Figure 1 the line bounds mean O_3 concentrations and exposure durations below which effects on plant growth and yield were not detected. This graphical analysis used data from both greenhouse and field studies and indicated that the lower limit for reduced plant performance was a mean O_3 concentration of 0.05 ppm for several hours per day for exposure periods greater than 16 days. At 10 days the O_3 response threshold increased to about 0.10 ppm and 0.30 ppm at 6 days.

METHODS FOR DETERMINING O_3 YIELD LOSSES

Diverse experimental procedures have been used to study the effects of O_3 on plants, ranging from studies in highly controlled conditions to exposures in open-top chambers and field exposures without chambers. In general, the more controlled conditions are most appropriate for investigating specific responses and providing the scientific basis for interpreting and extrapolating results. These systems are powerful tools to increase our understanding of the biological effects of air pollutants. However, to assess the impact of O_3 on plant yield it is desirable to minimize deviations from the typical environment in which the plant is grown. For field crops this implies that the studies should be conducted in the field but for crops that are typically grown in glass houses, the studies should be conducted under glass house conditions.

To improve estimates of yield loss in the field the National Crop Loss Assessment Network (NCLAN) was initiated by EPA in 1980 to estimate the magnitude of crop losses caused by O_3 (Heck et al., 1982). The primary objectives of NCLAN were:

1. to define the relationships between yields of major agricultural crops and O_3 exposure as required to support the needs of the economic assessments and the development of National Ambient Air Quality Standards;

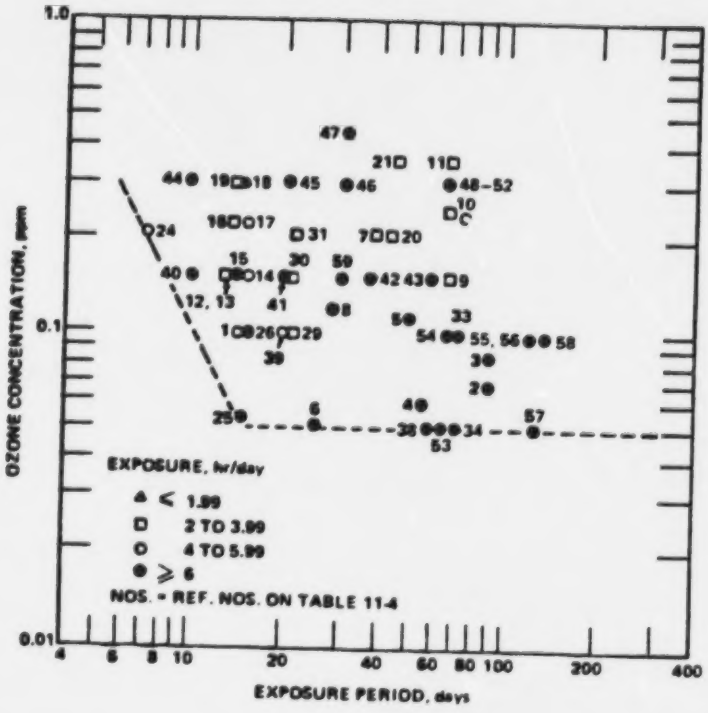

Figure 1. Relationship between O_3 concentration, exposure duration and a reduction in plant growth or yield. The numbers on the figure refer to reference numbers from Table 11-4 and the figure is from Chapter 11 in U.S. EPA (1978).

2. to assess national economic consequences resulting from the exposure of major agricultural crops to O_3;

3. to advance the understanding of the cause and effect relationships that determine crop responses to pollutant exposures.

The NCLAN experimental sites were selected on the basis of 1) differing climatic conditions, 2) distribution of crop species and 3) the existence of established research groups studying air pollution effects on plants. Cultural conditions approximate typical agronomic practices and open-top field exposure chambers are used to minimize perturbations to the plant environment during the exposure. The studies have attempted to use realistic O_3 concentrations and sufficient replication to permit the development of exposure-response models. The data have been analyzed using regression approaches. The exposures are characterized by a 7-h (09:00 to 16:00) seasonal mean O_3 concentration. This is the time period when O_3 is added to the exposure chambers.

ESTIMATES OF YIELD LOSS

Studies, frequently using open-top field exposure chambers, have been conducted to estimate the impact of O_3 on the yield of various crop species. These studies can be grouped into two types, depending on the experimental design and statistical methods used to analyze the data: 1) studies that developed predictive equations relating O_3 exposure to plant response and 2) studies which compared discrete treatment levels to a control. The advantage of the regression approach is that exposure-response models can be used to interpolate results between treatment levels.

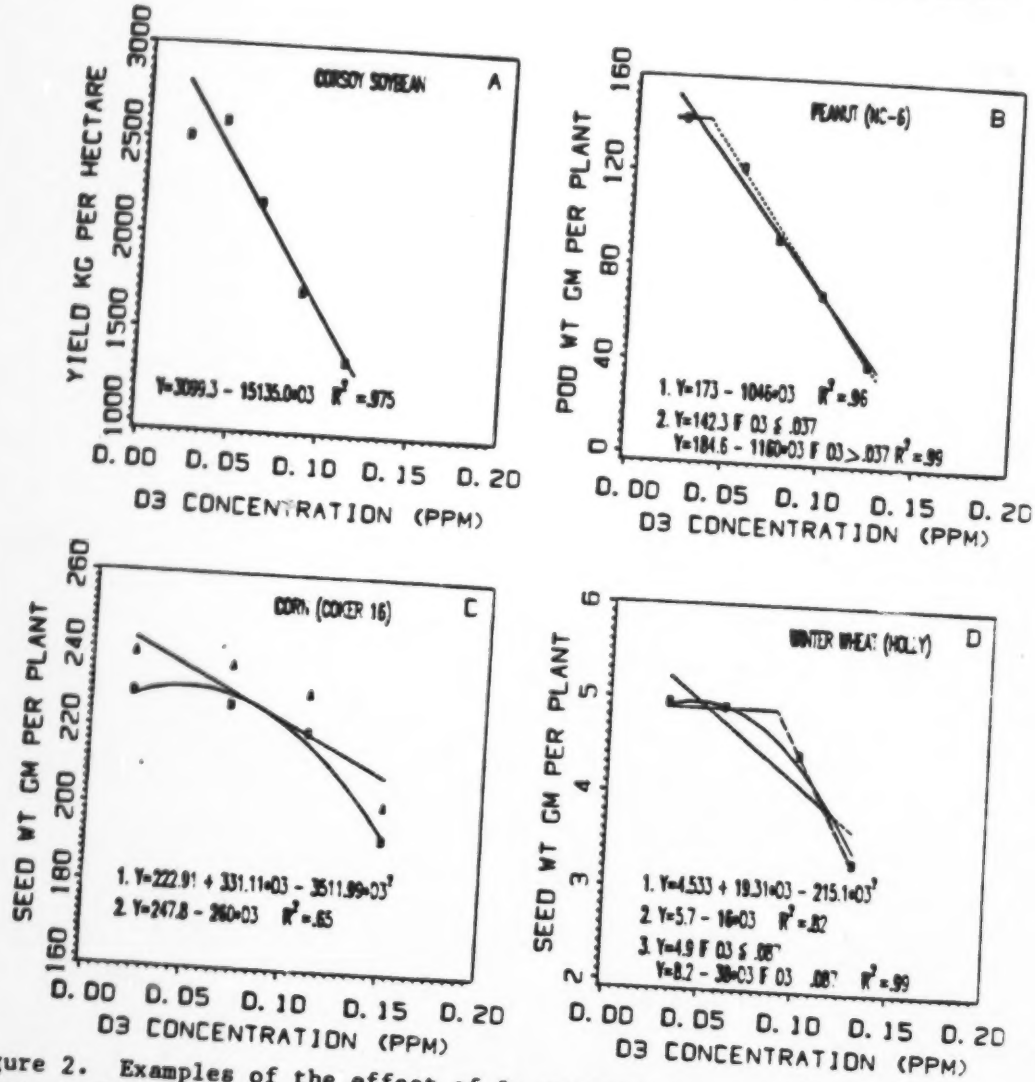

Figure 2. Examples of the effect of O_3 exposure on the yield of various plants. The O_3 concentration (ppm) is expressed as the 7-h seasonal mean. Soybean (A) data from Kress and Miller (1983), Peanut (B) data from Heagle et al. (1983) and Heck et al. (1982), Corn (C) and Wheat (D) data from Heagle and Heck (1980) and Heck et al. (1982).

When the regression approach was used to estimate yield loss, O_3 was added to either charcoal-filtered or ambient air to create a range of O_3 concentrations. In summarizing the data, O_3-induced yield loss was derived from a comparison of the performance of the plants in charcoal-filtered air, although other reference concentrations have been used. Various regression techniques have been used to derive exposure-response functions. The use of regression approaches permits the estimation of the O_3 impact on plant yield over the range of concentrations, not just at the treatment means as is the case with analysis of variance methods. Graphs of exposure-response equations and the data used to derive them show the fit of the various models to the experimental data (Figure 2).

Linear regression equations have been used to estimate yield loss but for some species and cultivars there appear to be systematic deviations from the data even though the equations had high coefficients of determination (R2). The use of plateau-linear or polynomial equations appeared to fit the data better. More recently a Weibull model has been used to estimate percent yield loss (Heck et al., 1983). The Weibull model yields a curvilinear response line which seems to provide reasonable fit to the data. This model has also been used to develop yield response equations, combining the responses for several cultivars of a species (Figure 3). Statistical analysis indicated that for most crops the model fit the combined data as well as the data for the individual cultivars. Yield loss estimates for some major crop species were made using the combined models; it appears that O_3 impacts the yield of corn and wheat much less than it does the yields of cotton, soybeans and peanuts.

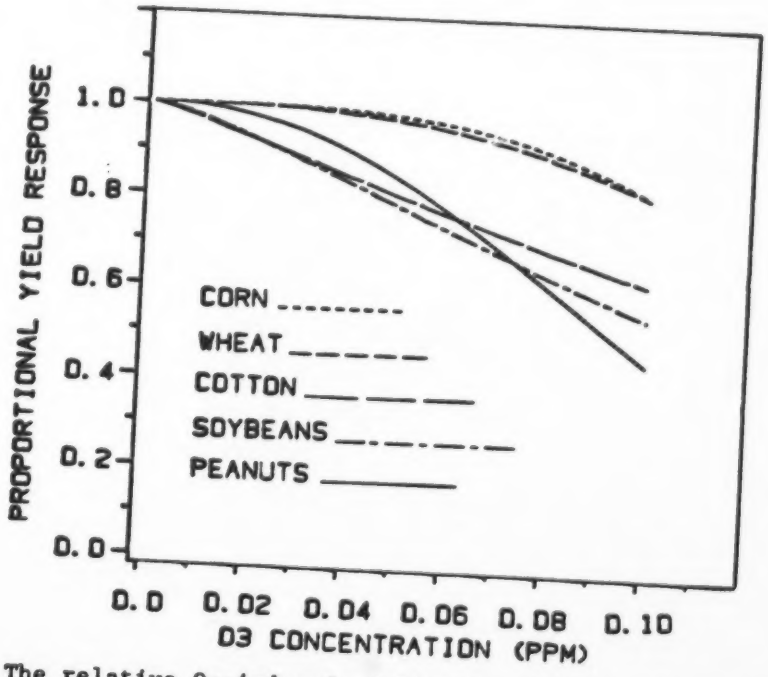

Figure 3. The relative O_3-induced yield reduction of selected crops as predicted by the Weibull model (Heck et al., 1983).

The yield response models can be used to estimate the O_3 concentrations that induce losses (e.g. 10 and 30%) in various plant species and cultivars (Table 2). In general, when several models were fit to the data they tended to predict similar concentrations that induced yield losses. However, in the case of corn, turnip and winter wheat, the linear model tended to underestimate the O_3 concentrations that would cause 10 or 30% yield reductions. The similarity among the estimated concentrations for a given cultivar suggests that the predicted values are influenced to a greater extent by the original data than by the model used to describe the data. A brief review of the data (Table 2) indicates that for several species, mean yield reductions (10%) were predicted when the 7-h seasonal mean O_3 concentration exceeded 0.04 to 0.05 ppm.

In addition to the studies which used regression approaches, various other approaches have been used to investigate the effects of O_3 on crop yield. These studies were designed to test where specific O_3 treatments were different from the control rather than to develop exposure-response equations. In general these data were analyzed using analysis of variance. To summarize the data from studies that used discrete treatments, the lowest O_3 concentration that significantly reduced yield was determined from the author's analysis (Table 3). The lowest concentration reported to reduce yield was frequently the lowest concentration used in the study, hence it was not always possible to estimate a noeffect exposure condition. In general, the data indicate that O_3 concentrations of 0.10 ppm (frequently the lowest concentration used in the studies) for a few hours per day for several days to weeks generally caused significant yield reductions. Although it appears from this analysis that a higher O_3 concentration was required to cause an effect than estimated from the regression studies, it should be noted that the concentrations derived from the regression studies were based on a 10% yield loss while in studies using analysis of variance (Table 3) the 0.10 ppm concentration frequently induced mean yield losses of 10 to 50%.

YIELD LOSS FROM AMBIENT EXPOSURES

Of studies to determine the impact of ambient oxidants (primarily O_3) on plant yield, most have compared the yield differences between plants grown in ambient air and those grown in charcoal-filtered air. Early research documented that ambient oxidants reduced the yield and quality of citrus, grape, tobacco, cotton and potato (U.S. EPA, 1978). More recent studies substantiated the impacts of ambient oxidants on plant yield. Ozone induced significant yield reductions in tomato and bean (MacLean and Schneider, 1976), soybean (Howell et al., 1979), 2 sweet corn cultivars (Thompson et al., 1976) and forbes, grasses and sedges (Duchelle et al., 1983). Over several years, bean yields varied from a 5% increase to a 22% decrease in response to O_3 concentrations in excess of 0.06 ppm. (Heggestad and Bennett, 1981). Studies conducted on eastern white pine in the southern Appalachian mountains showed that ambient O_3 has reduced the radial growth of sensitive individuals 30 to 50% annually over the last 15 to 20 years (Mann et al., 1980; Benoit et al., 1982). Field studies in the San Bernardino National Forest showed that during the last 30 years ambient O_3 reduced height growth of ponderosa pine by

TABLE 2. SEASONAL 7-HOUR O_3 CONCENTRATIONS (PPM) AT WHICH YIELD LOSSES OF 10% OR 30% ARE PREDICTED FROM EXPOSURE-RESPONSE MODELS

Plants	Model	Control O_3 concentration	Yield Loss 10%	30%	Reference
Grains/Seeds					
Soybean					
(Corsoy)	Kg/ha = 3099.3 - 15135 x O_3	0.022	0.040	0.077	Kress & Miller, 1983
(Corsoy)	g/plant = 15.6 exp $[-(O_3/0.129)^{1.70}]$	0.022	0.043	0.076	Heck et al., 1983
(Davis)	seed wt/m = 534.5 - 3988.6xO_3+10960xO_3^2	0.025	0.038	0.070	Heagle et al., 1983
(Davis)	g/plant = 31.1 exp $[-(O_3.0.129)^{0.91}]$	0.025	0.038	0.071	Heck et al., 1983
(Essex)	g/plant = 18.7 exp $[-(O_3/0.309)^{0.76}]$	0.014	0.037	0.109	Heck et al., 1983
(Hodgson-F)*	g/plant = 15.2 exp $[-(O_3/0.207)^{0.50}]$	0.017	0.039	0.096	Heck et al., 1983
(Hodgson-P)*	g/plant = 15.5 exp $[-(O_3/0.153)^{1.57}]$	0.017	0.043	0.084	Heck et al., 1983
(Williams)	g/plant = 19.4 exp $[-(O_3/0.243)^{0.94}]$	0.014	0.038	0.098	Heck et al., 1983
Peanut - 1979	pod wt/plant = 112 - 563 x O_3	0.026	0.043	0.078	Heagle et al., 1983
Peanut - 1980+	pod wt/plant = 173 - 1046 x O_3	0.025	0.039	0.067	Heagle et al., 1983
Peanut - 1980	pod wt/plant = 142.3 if $O_3 \leq 0.037$; if $O_3 > 0.037$ PW/P = 184.6 - 1160 x O_3	0.025	0.049	0.073	Heck et al., 1982
Peanut - 1980	g/plant = 148 exp $[-(O_3/0.186)^{3.20}]$	0.025	0.046	0.073	Heck et al., 1983
Kidney bean	seed wt/plant = 17.44 - 35.51 x O_3	0.025	0.072	0.165	Kohut & Lawrence, 1983
Kidney bean	g/plant = 16.5 exp $[-(O_3/0.287)^{1.77}]$	0.025	0.086	0.164	Heck et al., 1983
Field corn					
(Coker 16)+	g/plant 247.8 - 260 x O_3	0.02	0.113	0.300	Heck et al., 1982
(Coker 16)	g/plant = 222.91+331.11 x O_3 - 3511.99 x O_3^2	0.02	0.132	-	Heagle & Heck, 1980
(Coker)	g/plant = 240 exp $[-(O_3/0.221)^{4.46}]$	0.02	0.133	0.175	Heck et al., 1983
(PAG 397)	g/plant = 166 exp $[-(O_3/0.160)^{4.28}]$	0.15	0.095	0.126	Heck et al., 1983
(Pioneer 3780)	g/plant = 149 exp $[-(O_3/0.155)^{3.11}]$	0.15	0.075	0.111	Heck et al., 1983
Winter wheat					
(Blueboy II)+	g/plant = 6.6 - 18 x O_3	0.03	0.063	0.131	Heck et al., 1982
(Blueboy II)	g/plant = 5.908 + 3.958 x O_3 - 137.7 x O_3^2	0.03	0.0187	0.129	Heagle & Heck, 1980
(Blueboy II)	g/plant = 5.88 exp $[-(O_3/0.175)^{3.22}]$	0.03	0.088	0.127	Heck et al., 1983
(Coker 47-27)+	g/plant = 5.8 - 21 x O_3	0.03	0.055	0.104	Heck et al., 1982
(Coker 47-27)	g/plant = 5.765 - 18.79 x O_3 - 20.00 x O_3^2	0.03	0.055	0.103	Heagle & Heck, 1980
(Coker 47-27)	g/plant = 5.19 exp - $[-(O_3/0.171)^{2.06}]$	0.03	0.064	0.107	Heck et al., 1983
(Holly)+	g/plant = 5.7 - 16 x O_3	0.03	0.063	0.128	Heck et al., 1982
(Holly)	g/plant = 4.533 + 19.31 x O_3 - 215.1 x O_3^2	0.03	0.095	0.129	Heagle & Heck, 1980
(Holly)	g/plant = 4.95 exp $[-(O_3/0.156)^{4.95}]$	0.03	0.099	0.127	Heck et al., 1983
(Holly)	g/plant = 4.9 if x $\leq$ 0.087 if $O_3 > 0.087$ g/p = 8.2 -38 O_3	0.03	0.100	0.126	Heck et al., 1982

TABLE 2. (continued)

Plants	Model	Control O_3 concentration	Yield 10%	Loss 30%	Reference
(Oasis)+	g/plant = 4.9 - 12 x O_3	0.03	0.068	0.143	Heck et al., 1982
(Oasis)	g/plant = 4.475 + 3.320 x O_3 - 93.49 x O_3^2	0.03	0.088	0.138	Heagle & Heck, 1980
(Oasis)	g/plant = 4.88 exp [-(O_3/0.186)$^{3.20}$]	0.03	0.093	0.135	Heck et al., 1983
Cotton	g/plant = 41.5 exp [-O_3/0.197)$^{1.12}$]	0.018	0.041	0.092	Heck et al., 1983
Root Crops					
Turnip (Just Right)+	edible rt wt/plant = 12.9 - 94 x O_3	0.014	0.026	0.051	Heck et al., 1982
(Just Right)	edible rt wt/plant = 10.7 if $O_3 \leq 0.038$ if $O_3 > 0.038$ = 15.5 - 127 x O_3	0.014	0.046	0.063	Heck et al., 1982
(Just Right)	g/plant = 10.89 exp [-(O_3/0.090)$^{3.05}$]	0.014	0.043	0.064	Heck et al., 1983
(Purple Top White Globe)	edible rt wt/plant = 7.2 - 49 x O_3	0.014	0.027	0.054	Heck et al., 1982
(Purple Top White Globe)	edible rt wt/plant = 6.0 if $O_3 \leq 0.034$ if > 0.034 ERW/P = 8.1 - 60 x O_3	0.014	0.045	0.065	Heck et al., 1982
(Purple Top White Globe)	g/plant = 6.22 exp [-(O_3/0.095)$^{2.51}$]	0.014	0.040	0.064	Heck et al., 1983
(Shogoin)	edible rt wt/plant = 5.3 - 36 x O_3	0.014	0.027	0.054	Heck et al., 1982
(Shogoin)+	g/plant = 4.68 exp [-(O_3/0.096)$^{2.12}$]	0.014	0.036	0.060	Heck et al., 1983
(Tokyo Cross)+	edible rt wt/plant = 18.1 - 116 x O_3	0.014	0.028	0.057	Heck et al., 1982
(Tokyo Cross)	edible rt wt/plant = 14.8 if $O_3 \leq 0.054$ if $O_3 > 0.054$ ERW/P = 27.0 - 226 x O_3	0.014	0.061	0.074	Heck et al., 1982
(Tokyo Cross)	g/plant = 15.25 exp [-(O_3/-.094)$^{3.94}$]	0.014	0.053	0.072	Heck et al., 1983
Foliage Crops					
Lettuce	fresh hd wt/plant = 1065.7 - 5978 x O_3	0.043	0.057	0.084	Heck et al., 1982
Lettuce	g/plant = 1245 exp [-(O_3/0.098)$^{1.22}$]	0.043	0.053	0.075	Heck et al., 1983
Spinach (America)	g/plant = 22.7 - 106 O_3 if $O_3 > 0.087$ g/p = 8.2 -38 O_3	0.024	0.043	0.081	Heck et al., 1982
(Winter Bloomsdale)	g/plant = 23.3 - 121 x O_3	0.024	0.041	0.075	Heck et al., 1982
(Winter Bloomsdale)	g/plant = 20.8 exp [-(O_3/0.127)$^{2.07}$]	0.024	0.049	0.080	Heck et al., 1983
(Hybrid 7)	g/plant = 42.1 - 193 x O_3	0.024	0.043	0.082	Heck et al., 1982
(Hybrid 7)	g/plant = 36.6 exp [-(O_3/0.139)$^{2.68}$]	0.024	0.060	0.095	Heck et al., 1983
(Viroflay)	g/plant = 46.1 - 238 x O_3	0.024	0.041	0.075	Heck et al., 1982
(Viroflay)	g/plant = 41.1 exp [-(O_3/0.129)$^{1.99}$]	0.024	0.048	0.080	Heck et al., 1983

* The Hodgson data were obtained from two designs in 1981; a full harvest (F) and a partial plot harvest (P), where some plants were removed prior to harvest.

+ This model did not fit the data well and tended to underestimate the O_3 concentrations which cause yield losses.

TABLE 3. OZONE CONCENTRATIONS AT WHICH SIGNIFICANT YIELD LOSSES HAVE BEEN NOTED FOR A VARIETY OF PLANT SPECIES EXPOSED TO O_3 UNDER VARIOUS EXPERIMENTAL CONDITIONS

Plant species	Exposure duration	Yield reduction % of control	O_3 concentration (ppm)	Reference
Alfalfa	7 h/d, 70 d	51, top dry wt	0.10	Neely et al., 1977
Alfalfa	2 h/d, 21 d	16, top dry wt	0.10	Hoffman et al., 1975
Pasture grass	4 h/d, 5d/wk, 5 wk	20, top dry wt	0.09	Horsman et al., 1980
Ladino clover	6 h/d, 5 d	20, shoot dry wt	0.10	Blum et al., 1982
Soybean	6 h/d, 133 d	55, seed wt/plant	0.10	Heagle et al., 1974
Sweet corn	6 h/d, 64 d	45, seed wt/plant	0.10	Heagle et al., 1972
Sweet corn	3 h/d, 3 d/wk, 8 wk	13, ear fresh wt	0.20	Oshima, 1973
Wheat	4 h/d, 7 d	30, seed yield	0.20	Shannon & Mulchi, 1974
Radish	3 h	33, root dry wt	0.25	Adedipe & Ormrod, 1974
Beet	2 h/d, 38 d	40, storage root dry wt	0.20	Ogata & Maas, 1973
Potato	3 h/d, every 2 wk, 120 d	25, tuber wt	0.20	Pell et al., 1980
Pepper	3 h/d, 3 d/wk, 11 wk	19, fruit dry wt	0.12	Bennett et al., 1979
Cotton	6 h/d, 2 d/wk, 13 wk	62, fiber dry wt	0.25	Oshima et al., 1979
Carnation	24 h/d, 12 d	74, no. of flower buds	0.05-0.09	Feder & Campbell, 1968
Coleus	2 h	20, flower no.	0.20	Adedipe et al., 1972
Begonia	4 h/d, once every 6 d for a total of 4 times	55, flower wt	0.25	Reinert & Nelson, 1979
Ponderosa pine	6 hr/d, 126 d	21, stem dry wt	0.10	Wilhour & Neely, 1977
Western white pine	6 h/d, 126 d	9, stem dry wt	0.10	Wilhour & Neely, 1977
Loblolly pine	6 h/d, 28 d	18, height growth	0.05	Wilhour & Neely, 1977
Pitch pine	6 h/d, 28 d	13, height growth	0.10	Wilhour & Neely, 1977
Poplar	12 h/d, 5 mo	+1333, leaf abscission	0.041	Wilhour & Neely, 1977
Hybrid poplar	12 h/d, 102 d	58, height growth	0.15	Patton, 1981
Hybrid poplar	8 h/d, 5 d/wk, 6 wk	50, shoot dry wt	0.15	Patton, 1981
Red maple	8 h/d, 6 wk	37, height growth	0.25	Dochinger & Townsend, 1979
American sycamore	6 h/d, 28 d	9, height growth	0.05	Kress & Skelly, 1982
Sweetgum	6 h/d, 28 d	29, height growth	0.10	Kress & Skelly, 1982
White ash	6 h/d, 28 d	17, total dry weight	0.15	Kress & Skelly, 1982
Green ash	6 h/d, 28 d	24, height growth	0.10	Kress & Skelly, 1982
Willow oak	6 h/d, 28 d	19, height growth	0.15	Kress & Skelly, 1982
Sugar maple	6 h/d, 28 d	12, height growth	0.15	Kress & Skelly, 1982

25%, radial growth by 37% and the total wood volume produced by 84% (Miller et al., 1982).

STATISTICS USED TO CHARACTERIZE O_3 EXPOSURES

The characterization and representation of plant exposures to O_3 has been, and continues to be, a major problem. Research has not yet clearly identified which components of the pollutant exposure cause the plant response. Most studies have characterized the exposure by the use of mean O_3 concentrations although various averaging times have been used. Some studies have also used cumulative O_3 dose. The difficulty of selecting an appropriate statistic to characterize plant exposure has been summarized by Heagle and Heck (1980). Ambient and experimental O_3 exposures have been presented as seasonal, monthly, weekly or daily means; peak hourly means; number of hours above a selected concentration; or the number of hours above selected concentration intervals. None of these statistics adequately characterized the relationships among O_3 concentration, exposure duration, interval between exposures and plant response. The use of a mean concentration implies that all concentrations of O_3 are equally effective in causing plant responses and minimizes the contributions of the peak concentrations to the response. The mean treats low-level long-term exposures the same as high-concentration short-term ones. Most of the exposure statistics are not directly correlated with each other and it is difficult to relate them to ambient air measurements of O_3 which are usually reported as 1-h means. Also it is difficult to transform one exposure statistic to another without re-analyzing the original air monitoring data.

Studies with beans and tobacco (Heck et al., 1966) showed that a dose (concentration x time) over a short period induced more injury than when the same dose was distributed over a longer period. In beans foliar injury occurred when the internal O_3 flux exceeded 5500 $\mu g\ m^{-2}$ in 1-hr (Bennett, 1979).. However, a single 3-h exposure at approximately half the concentration (0.27 compared with 0.49 ppm) required a 64% greater internal flux of O_3 to induce the same amount of foliar injury as the 1-h exposure. The greater importance of concentration compared to exposure duration has been reported by numerous authors (e.g. Heck and Tingey, 1971; Henderson and Reinert, 1979; Reinert and Nelson, 1979).

Not only are concentration and time important but also the dynamic nature of the O_3 exposure, i.e. is the exposure at a constant or variable concentration? Musselman et al. (1983) recently showed that constant concentrations of O_3 caused the same types of plant responses as variable concentrations at equivalent doses. But, the variable concentration exposures caused a greater plant effect than the constant exposures. Recent studies with alfalfa confirmed that plants which experienced episodic exposures displayed a greater yield loss than did plants exposed daily to elevated O_3 concentrations (W.E. Hogsett, unpublished data). In soybeans plant effects were most closely correlated with the number of O_3 peaks in excess of 0.10 ppm (Pratt, 1982). Studies with SO_2 also showed that plants exposed to variable concentrations exhibited a greater plant response than those exposed to a constant concentration (McLaughlin et al., 1979; Male et al., 1983).

RELATION BETWEEN YIELD LOSS AND FOLIAR INJURY

Because plant growth and production depends on photosynthetically functional leaves, various studies have been conducted to determine the association between foliar injury and yield for species in which the foliage is not part of the yield. Some research has demonstrated significant yield loss with little or no foliar injury (e.g. Tingey et al., 1971; Tingey and Reinert, 1975; Kress and Skelly, 1982; Feder and Campbell, 1968; Adedipe et al., 1972). Other studies showed that significant foliar injury was not always associated with yield loss (Heagle et al., 1974; Oshima et al., 1975). The relative sensitivities of two potato cultivars were reversed when judged by foliar injury or yield reductions (Pell et al., 1980). In field corn, foliar injury occurred at a lower O_3 concentration than yield reductions but as the O_3 concentration increased, yield was reduced to a greater extent than foliar injury was increased (Heagle et al., 1979a). In wheat foliar injury was not a good predictor of O_3-induced yield reductions (Heagle et al., 1979b).

CONCLUSION

Ozone has been identified as the most important phytotoxic air pollutant in terms of area impacted and as a cause of reduced plant performance. Ozone is an imposed environmental variable that can be detected, monitored and sometimes quantified by observing specific responses on sensitive plants. Ozone impacts a wide range of plant species; these O_3-sensitive species and cultivars are distributed thoughout the United States. Although O_3 has been shown to reduce plant yields, more research is needed to estimate yield loss for additional cultivars and species. More information is needed to determine the characteristics of the exposure that are most important in causing a plant response. Studies need to be conducted to determine the influence of major environmental factors on O_3-response thresholds.

REFERENCES

Adedipe, N. O., Barrett, R. E., and Ormrod, D. P. (1972) Phytotoxicity and growth responses of ornamental bedding plants to ozone and sulfur dioxide. J. Am. Soc. Hort. Sci., 97, 341-345

Adedipe, N. O., Ormrod, D. P. (1974) Ozone induced growth supression in radish plants in relation to pre- and post-fumigation temperatures. Z. Pflanzen Physiol., 71, 281-287

Bennett, J. H. (1979) Foliar exchange of gases. pp 10-1 to 10-29 In Handbook of Methodology for the Assessment of Air Pollution Effects on Vegetation. Heck, W. W., Krupa, S. K., and Linzon, S. N., Eds. Air Pollution Control Association, Pittsburgh

Bennett, J. P., Oshima, R. J., and Lippert, L. F. (1979) Effects of ozone on injury and dry matter partitioning in pepper plants. Environ. Exp. Bot., 19, 33-39

Benoit, L. F., Skelly, J. M., Moore, L. D., and Dochinger, L. S. (1982) Radial growth reductions in Pinus strobus L. correlated with foliar ozone sensitivity as an indicator of ozone induced losses in eastern forests. Can. J. For. Res., 12, 673-678

Blum, U. T., Smith, G. R., and Fites, R. C. (1982) Effects of multiple O_3 exposures on carbohydrate and mineral contents of Ladino clover. Enviro. Exp. Bot., 22, 143-154

Dochinger, L. S., and Townsend, A. M. (1979) Effects of roadside deicer salts and ozone on red maple progenies. Environ. Pollut., 19, 229-237

Duchelle, S. F., Skelly, J. M., Charick, T. L., Chevone, B. I., Yang, Y. S., and Nellessen, J. E. (1983) Effects of ozone on the productivity of natural vegetation in a high meadow of the Shenandoah National Park of Virginia. J. Environ. Manage., 17, 299-308

Feder, W. A., and Campbell, F. J. (1968) Influence of low levels of ozone on flowering of carnations. Phytopathology 58, 1038-1039

Heagle, A. S., Body, D. E., and Neely, G. E. (1974) Injury and yield responses of soybean to chronic doses of ozone and sulfur dioxide in the field. Phytopathology 64, 132-136

Heagle, A. S., Body, D. E., and Pounds, E. K. (1972) Effect of ozone on yield of sweet corn. Phytopathology 62, 683-687

Heagle, A. S., and Heck, W. W. (1980) Field methods to assess crop losses due to oxident air pollutants. pp 296-305 In Crop Loss Assessment: Proceedings of E. C. Stakman Commemorative Symposium. Teng, P. S., and Krupa, A. V., Eds. University of Minnesota, Agricultural Experimental Station; Miscellaneous Publication No. 7, Minneapolis

Heagle, A. S., Letchworth, M. B., and Mitchell, C. A. (1983) Injury and yield responses of peanuts to chronic doses of ozone in open-top field chambers. Phytopathology 73, 551-555

Heagle, A. S., Philbeck, R. B., and Knott, W. M. (1979a) Thresholds for injury growth, and yield loss caused by ozone on field corn hybrids. Phytopathology 69, 21-26

Heagle, A. S., Spencer, S., and Letchworth, M. B. (1979b) Yield response of winter wheat to chronic doses of ozone. Can. J. Bot., 57, 1999-2005

Heck, W. W., Adams, R. M., Cure, W. W., Heagle, A. S., Heggestad, H. E., Kohut, R. J., Kress, L. W., Rawlings, J. O., and O. C. Taylor. (1983) A reassessment of crop loss from ozone. Environ. Sci. Tech., 17, 573A-581A

Heck, W. W., Dunning, J. A., and Hindawi, I. J. (1966) Ozone: Non-linear relation of dose and injury in plants. Science 151, 577-578

Heck, W. W., Taylor, O. C., Adams, R., Bingham, G., Miller, J., Preston, E., and Weinstein, L. (1982) Assessment of crop loss from ozone. J. Air. Pollut. Control Assoc., 32, 353-361

Heck, W. W., and Tingey, D. T. (1971) Ozone time-concentration model to predict acute foliar injury. pp 249-255 In Proceedings of the Second International Clean Air Congress. Englund, H. M., and Beery, W. T., Eds. Academic Press, New York

Heggestad, H. E., and Bennett, J. H. (1981) Photochemical oxidants potentiate yield losses in snap beans attributable to sulfur dioxide. Science 213, 1008-1010

Henderson, W. R., and Reinert, R. A. (1979) Yield response of four fresh market tomato cultivars after acute ozone exposure in the seedling stage. J. Amer. Soc. Hortic. Sci., 104, 754-759

Hoffman, G. J., Maas, E. V., and Rawlins, S. L. (1975) Salinity-ozone interactive effects on alfalfa yield and water relations. J. Environ. Qual., 4, 326-331

Horsman, D. C., Nocholls, A. O., and Calder, D. M. (1980) Growth responses of Dactylis glomerata, Lolium perenne, and Phalaris aquatica to chronic ozone exposure. Aust. J. Plant Physiol., 7, 511-517

Howell, R. K., Kock, E. J., and Rose, L. P. (1979) Field assessment of air pollution induced soybean yield losses. Agron. J., 71, 285-288

Jacobson, J. S. (1977) The effects of photochemical oxidants on vegetation. pp 163-173 In Ozone und Begleitsubstanzen im Photochemischen Smog. VDI BER. (270)

Kohut, R., and Laurence, J. A. (1983) Yield response of red kidney bean to incremental ozone concentrations in the field. Environ. Pollut. (Ser A), 32, 233-240

Kress, L. W., and Miller, J. E. (1983) Impact of ozone on soybean yield. J. Environ. Qual., 12, 276-281

Kress, L. W., and Skelly, J. M. (1982) Reponse to several eastern forest tree species to chronic doses of ozone and nitrogen dioxide. Plant Dis. Rep., 66, 1149-1152

Male, L., Preston, E., and Neely, G. (1983) Yield response curves of crops exposed to SO_2. Atmos. Environ., 17, 1589-1593

MacLean, D. C., and Schneider, P. E. (1976) Photochemical oxidants in Yonkers, New York. J. Environ. Qual., 5, 75-78

Mann, L. K., McLaughlin, S. B., and Shriner, D. S. (1980) Seasonal physiological reponses of white pine under chronic air pollution stress. Environ. Exp. Bot., 20, 99-105

McLaughlin, S. B., Shriner, D. S., McConathy, R. K., and Mann, L. K. (1979) The effects of SO_2 dosage kinetics and exposure frequency on photosynthesis and transpiration of kidney beans (Phaseolus vulgaris L.). Environ. Exp. Bot., 19, 179-191

Miller, P. R., Taylor, O. C., and Wilhour, R. G. (1982) Oxidant air pollution effects on a western coniferous forest ecosystem. EPA-600/D-82-276. U.S. Environmental Protection Agency, Corvallis, Oregon

Musselman, R. C., Oshima, R. J., and Gallavan, R. E. (1983) Significance of pollutant concentration distribution on the response of red kidney beans to ozone. J. Amer. Soc. Hort. Sci., 108, 347-351.

Neely, G. E, Tingey, D. T., and Wilhour, R. G. (1977) Effects of ozone and sulfur dioxide singly and in combination on yield, quality, and N-fixation of alfalfa. pp 663-673 In International Conference on Photochemical Oxidant Pollution and its Control. Proceedings. Volumn II. B. Dimitriades, Ed. EPA-600/3-77-001b. U. S. Environmental Protection Agency, Research Triangle Park, N.C.

Ogata, G., and Maas, E. V. (1973) Interactive effects of salinity and ozone on growth and yield of garden beet. J. Environ. Qual., 2, 518-520

Ormrod, D. P. (1982) Air pollutant interactions in mixtures. pp 307-331 In Effects of Air Pollution in Agriculture and Horticulture. Unsworth, M. H., and Ormrod, D. P., Eds. Butterworths, London

Oshima, R. J. (1973) Effects of ozone on a commercial sweet corn variety. Plant Dis. Rep., 57, 719-723

Oshima, R. J., Braegelmann, P. K., Flagler, R. B. and Teso, R. R. (1979) The effects of ozone on the growth, yield, and partitioning of dry matter in cotton. J. Environ. Qual., 8, 474-479

Oshima, R. J., Taylor, O. C., Braegelmann, P. K., and Baldwin, D. W. (1975) Effects of ozone on the yield and plant biomass of a commercial variety of tomato. J. Environ. Qual., 4, 463-464

Patton, R. L. (1981) Effects of ozone and sulfur dioxide on height and stem specific gravity of Populus Hybrids. For. Sci. Res. Paper NE-471.

Pell, E. J., Weissberger, W. C., and Speroni, J. J. (1980) Impact of ozone on quantity and quality of greenhouse-grown potato plants. Environ. Sci. Technol., 14, 568-571

Pratt, G. C. (1982) Effects of ozone and sulfur dioxide on soybeans. PhD Thesis. University of Minnesota, Minneapolis

Reinert, R. A., and Nelson, P. V. (1979) Sensitivity and growth of twelve elatior begonia cultivars to ozone. HortScience 14, 747-748

Shannon, J. G., and Mulchi, C. L. (1974) Ozone damage to wheat varieties at anthesis. Crop Sci., 14, 335-337

Thomas, M. D., Hendericks, R. H., and Hill, G. R. (1950) Sulfur metabolism of plants. Effects of sulfur dioxide on vegetation. Industrial and Engineering Chemistry, 42, 2231-2235

Thompson, C. R., Kats, G., and Camerson, J. W. (1976) Effects of ambient photochemical oxidants on growth, yield and ear characteristics of two sweet corn hybrids. J. Environ. Qual., 5, 410-412

Tingey, D. T. (1977) Ozone induced alterations in plant growth and metabolism. pp 601-609 In International Conference on Photochemical Oxidant Pollution and its Control: Proceedings, Volume II, January 1977. Dimitriades, B., Ed. EPA-600/3-77-001b. U.S. Environmental Protection Agency, Research Triangle Park, N.C.

Tingey, D. T., Heck, W. W., and Reinert, R. A. (1971) Effects of low concentrations of ozone and sulfur dioxide on foliage, growth and yield of radish. J. Am. Soc. Hort. Sci., 96, 369-371

Tingey, D. T., Reinert, R. A. (1975) The effects of ozone and sulfur dioxide singly and in combination on plant growth. Environ. Pollut., 9, 117-125

Tingey, D. T., and Taylor, G. E. (1982) Variation in plant response to ozone: a conceptual model of physiological events. pp 113-138 In Effects of Gaseous Air Pollution in Agricultural and Horticulture. Unsworth, M. H., and Ormrod, D. P., Eds. Butterworths, London

U.S. Environmental Protection Agency. (1978) Air quality criteria for ozone and other photochemical oxidants. EPA-600/8-78-004. Research Triangle Park, N.C.

Wilhour, R. G., and Neely, G. E. (1977) Growth response of conifer seedlings to low ozone concentrations. pp. 635-645 In International Conference of Photochemical Oxident Pollution and Its Control: Proceedings. Volume II. B. Dimitriades, Ed. EPA-600/3-77-001b. U.S. Environmental Protection Agency, Research Triangle Park, N.C.

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